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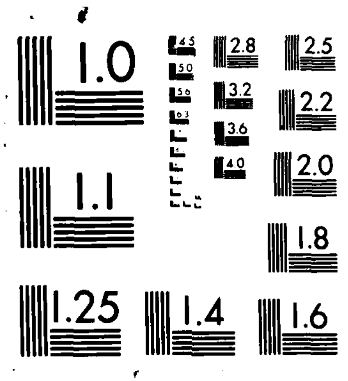
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OPTICAL PROPERTIES OF COMPRESSIBLE INHOMOGENEOUS SHEAR LAYERS RELEVANT TO HIGH POWER LASERS

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Walter H. Christiansen, Principal Investigator

ABSTRACT

Shear layers and wakes are a major source of optical degradation in flow lasers. The structure of these flows is being studied experimentally with special attention given to their optical properties. Gases with different refractive indices will be investigated and the effects of density ratio and Mach number on optical performance are being measured.

I. INTRODUCTION

Fluid mechanics is involved in many lasing processes and the flow field must be of excellent optical quality so that a near-diffraction-limited laser beam may be attained. With the general trend of laser development towards shorter wavelengths, the fluid optics challenge is increased considerably. In general, conditioning of the gas in the laser cavity or external flow effects continue to be a problem area. There are numerous instances where laser beams encounter turbulent interfaces in high power gas laser technology. Shear layers and wakes occur in the resonators of most high power laser systems and in external flows away from the transmitter. The extraction of power from a laser cavity usually invoves passing the beam through interfaces which often involve gases of different optical properties.

We are studying the fluid mechanical optical properties of inhomogeneous shear lasers. The 2-D inhomogeneous shear layer is chosen for a number of reasons. It is a simple and well studied flow at low Mach number, M. However, there is no experimental optical data which concentrates on the coherent effects produced by the layer and the extent of the mixing interface on optics. Part of the research involves studying the properties of single two-dimensional shear layers at high Mach numbers and Reynolds numbers appropriate for high power lasers. Experimentally this involves a systematic investigation with independent control of density ratio and compressibility effects of the free jets. The optical quality of each shear layer is being examined by looking at the far-field diffraction pattern of laser beams passing through the layer.

II. PROGRESS DURING CURRENT PROGRAM YEAR

Shear layer growth rates for jet Mach numbers of 0.1 to 2.0 were measured using a Mach-Zehnder and a shearing interferometer using a He-Ne laser source. Pulsed schlieren pictures were also taken of these flows. Some of the results have been compared with data available in the literature at very low Mach numbers and good agreement was achieved. A series of stop action Mach-Zehnder interferograms of shear layers at Mach numbers up to 1.4 were also taken and some interesting features were observed. Helium jets at (M=0.9 and M=1.4) radiated sound waves since the speed of the jet was greater than the speed of sound in the ambient air.

Fig. 1 shows representative stop-action schlieren pictures taken parallel to the shear layer. The high speed jet is to the left, discharging into still, ambient air. The photographs are representative of results obtained at Mach numbers (M) of 0.6, 0.9 and 1.4 and density ratios (λ_ρ) of 0.44 to 7.2. The gases used were He, Ar, He-Ar mixtures and CO_2. A few pictures were also taken at M=0.1 at λ_ρ = 0.2 using SF_6 as the test gas. These are not shown.

The shear layer spreading rates can be seen to decrease significa...ly with increasing M (compare along the columns of Fig. 1). A density ratio effect (spreading rates decreasing with increasing λ_ρ) can also be seen in Fig. 1 (compare along rows in Fig. 1). Acoustic radiation has been noted in the air outside the shear layer for very high jet speeds of He (e.g., M=1.4, λ_ρ=4.38 in Fig. 1). Large scale coherent structures[1] of the type well known in low speed shear layers were very obvious at M=0.1 (not shown in Fig. 1), were progressively less apparent at M=0.6 and M=0.9 and were apparently absent at M=1.4. (See particularly the last column of Fig. 1.) The gentle,

sinuous bending of the shear layer apparent in Fig. 1 for M=1.4 and λ_ρ=0.67 and λ_ρ=0.44 is not considered to be the same type of structure observed in low speed shear layers.

The other important aspect of this project is to investigate optical properties of two-dimensional shear layers. Stop-action interferograms viewed normal to the turbulent interface have been taken for all the test gases and three Mach numbers. Such data provide near-field phase information. Fig. 2 shows representative ruby stop-action interferograms taken normal to the shear layer. Conditions for Fig. 2 are identical to those for Fig. 1. The near-field phase errors shown in Fig. 2 are very large for the He jets (column 1), less for the CO_2 and Ar jets (column 3) and very small for the He-Ar mixtures which approach the index-matched condition (column 2).

The laser light passing through the mixing layer is perturbed due to refraction. The beam degradation is given by[2]

$$\frac{\Delta I}{I_0} \equiv \frac{I - I_0}{I_0} = \exp(-\overline{\Delta\phi^2})$$

where I_0 and I are the peak intensities for unaberrated and degraded beams in the far-field, respectively. The mean square phase perturbation, $\overline{\Delta\phi^2}$, can be calculated by analyzing a near-field interferogram. A package of software for automated data reduction using digital reading and processing of interferograms on an Apple II computer was developed and published.[3] Then the averaged value of the phase error over a chosen region was computed. Finally, the root mean square of the phase error can be plotted as a function of downstream coordinate. With the aid of this program, we were able to calculate the phase degradation of a ruby laser beam as a function of the distance from the exit of nozzle.[4]

Preliminary data on the far-field of a circular laser beam resulting from its passage perpendicularly through an inhomogeneous shear layer are represented in Fig. 3. Schlieren photographs taken parallel to the shear layers produced under the same conditions are shown next to the far-field photographs. Two different sized parallel laser beams, one 0.5 cm in diameter and the other 1.0 cm in diameter, were used to produce the far-field photographs. Each beam was passed through a rectangular gas jet bounded on three sides by glass walls.[5] The beam entered the jet through the shear layer on the open side of the jet, centered between the two side walls, with the beam centerline 1 cm downstream of the nozzle opening. After passing through the shear layer and jet, the beam exited through the glass wall and was demagnified by a telescope. The resulting reduced beam was attenuated and allowed to expand for a distance of 1 m before it was placed directly on a photographic plate with an exposure time of 0.1 sec. The center of the modified Airy pattern image thus produced was overexposed in order to show outlying ring structure. These images may be compared to the tare data taken in an identical manner, except without the gas jet and shear layer, and are shown in Fig. 3.

In every case, but to a varying degree, the laser beam has been spread over a larger area as a result of having passed through the shear layer. A preliminary assumption is that the degree of spreading is related to the amount of structure in the shear layer turbulence, the size of the structure relative to the beam diameter, and the ratio of the jet gas density to that of the surrounding air. Circular symmetry is degraded in all of the patterns produced by the 1 cm diameter beam, but to a lesser degree for those produced by the 0.5 cm beam. Further, the amount of spreading, and blurring of the zeros between the bright rings, is related to the gas

density since these effects are most pronounced in the gases having a refractive index farthest from that of the surrounding air.

Experiments were carried out to investigate the optical properties of fast shear layers by means of far field diffraction patterns of a circular laser beam resulting from its passage through the layer. The focal plane energy distribution of the laser beam is the far field pattern that was measured as part of this program. For these experiments, two different sized parallel HeNe laser beams, one 0.5 cm in diameter and the other 0.1 cm in diameter, were used to produce the far-field photographs. After passing through the shear layer and jet, the beam exited through the glass wall and was demagnified by a telescope for convenience. The modified Airy pattern image was thus produced. These images were then compared to the tare data taken in an identical manner, except without the gas jet and shear layer.

In every case, but to a varying degree, the laser beam has been spread over a larger area as a result of having passed through the shear layer. A preliminary assumption is that the degree of spreading is related to the amount of structure in the shear layer turbulence, the size of the structure relative to the beam diameter, and the ratio of the jet gas density to that of the surrounding air. Circular symmetry is degraded in all of the patterns produced by the 1 cm diameter beam, but to a lesser degree for those produced by the 0.5 cm beam. Further, the amount of spreading, and blurring between the bright rings is most pronounced in the gases having a refractive index farthest from that of the surrounding air.

Optical quality measurements taken normal to the high subsonic flow shear layer were carried out using a cw HeNe light source to obtain time averaged results. The measurements concentrated on Strehl ratio and tilt aberration error.[2] These results were obtained by using a new electronic

digital image acquisition system. These measurements covering various Mach numbers, M, and density ratios, $\lambda\rho$, are published in two theses at the University by D. Higgins[6] and T. Blum.[7]

These results coupled with our previous shear layer measurements provided us with values of shear layer width to correlate with density ratio and Mach number. The near-field beam degradation may be related to the far-field intensity if the Strehl ratios are measured. Parameters such as the laser wave number, k, and the index refraction change, Δn, across the layer are known. The mean shear layer thickness, δ, is known from our published fluid mechanical experiments.[5] In the cases where no coherent structure is seen, the scale lengths may be assumed to be roughly proportional to the measured shear layer thickness. Under these conditions we may write the Strehl ratio as

$$\text{Strehl ratio} = \exp\left(-\overline{\Delta\phi^2}\right) \approx \exp\left(-Ak^2\Delta n^2\delta^2\right) .$$

Values of A are being found for the range of interest based on our measurements of δ and Strehl ratio. This correlation bases the far-field performance with fluid mechanical parameters that are defined with respect to the mean thickness of the shear layer.

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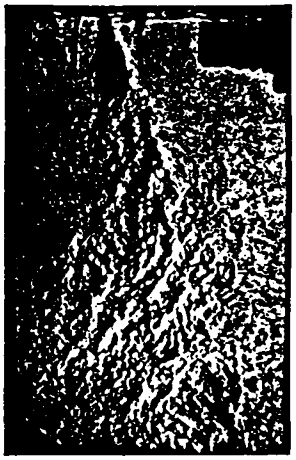
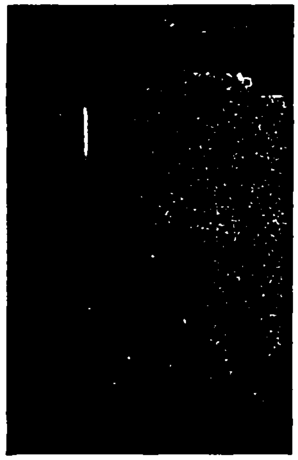
STOP ACTION SCHLIEREN PHOTOGRAPHS
PARALLEL TO SHEAR LAYER

$M = 0.6$



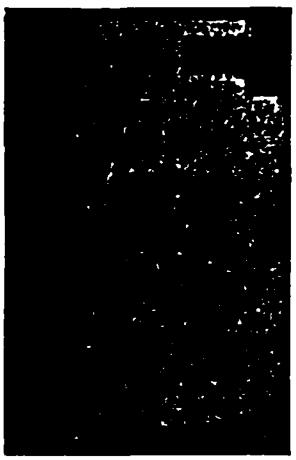
$\lambda_\rho = 6.47$



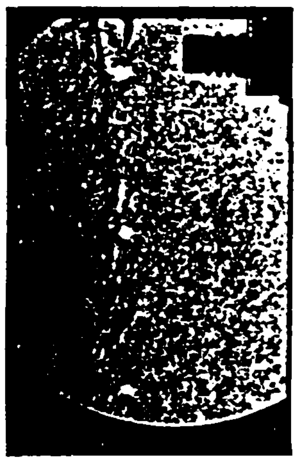
$\lambda_\rho = 0.98$

$\lambda_\rho = 0.62$

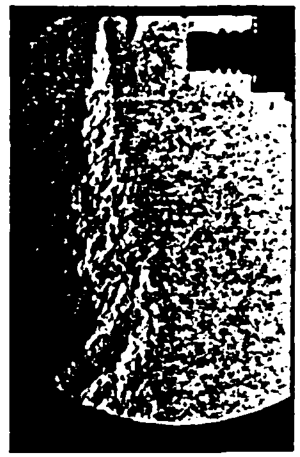
$M = 0.9$



$\lambda_\rho = 5.70$



$\lambda_\rho = 0.87$



$\lambda_\rho = 0.58$

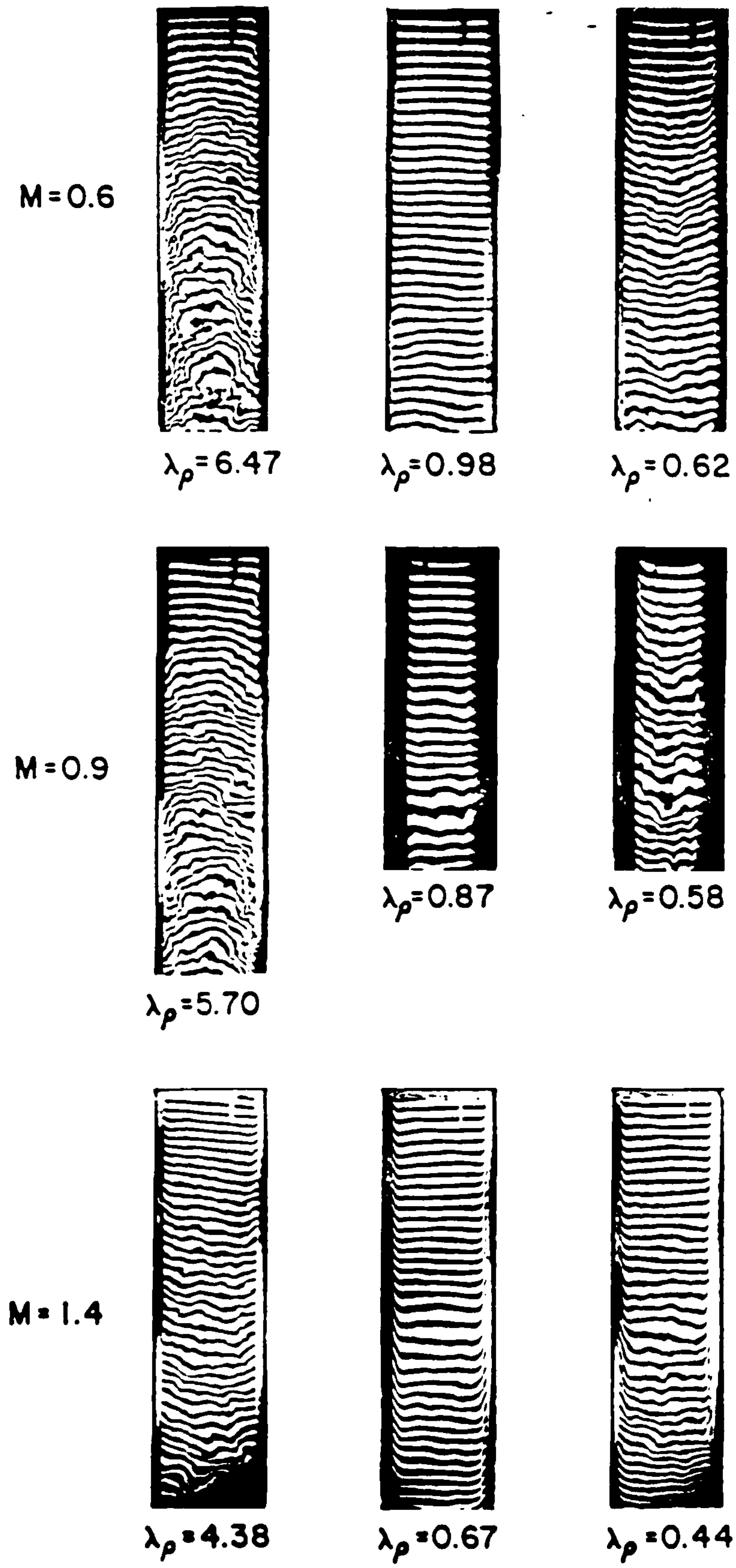
$M = 1.4$

$\lambda_\rho = 4.38$

$\lambda_\rho = 0.67$

$\lambda_\rho = 0.44$

STOP ACTION INTERFEROGRAMS
NORMAL TO SHEAR LAYER



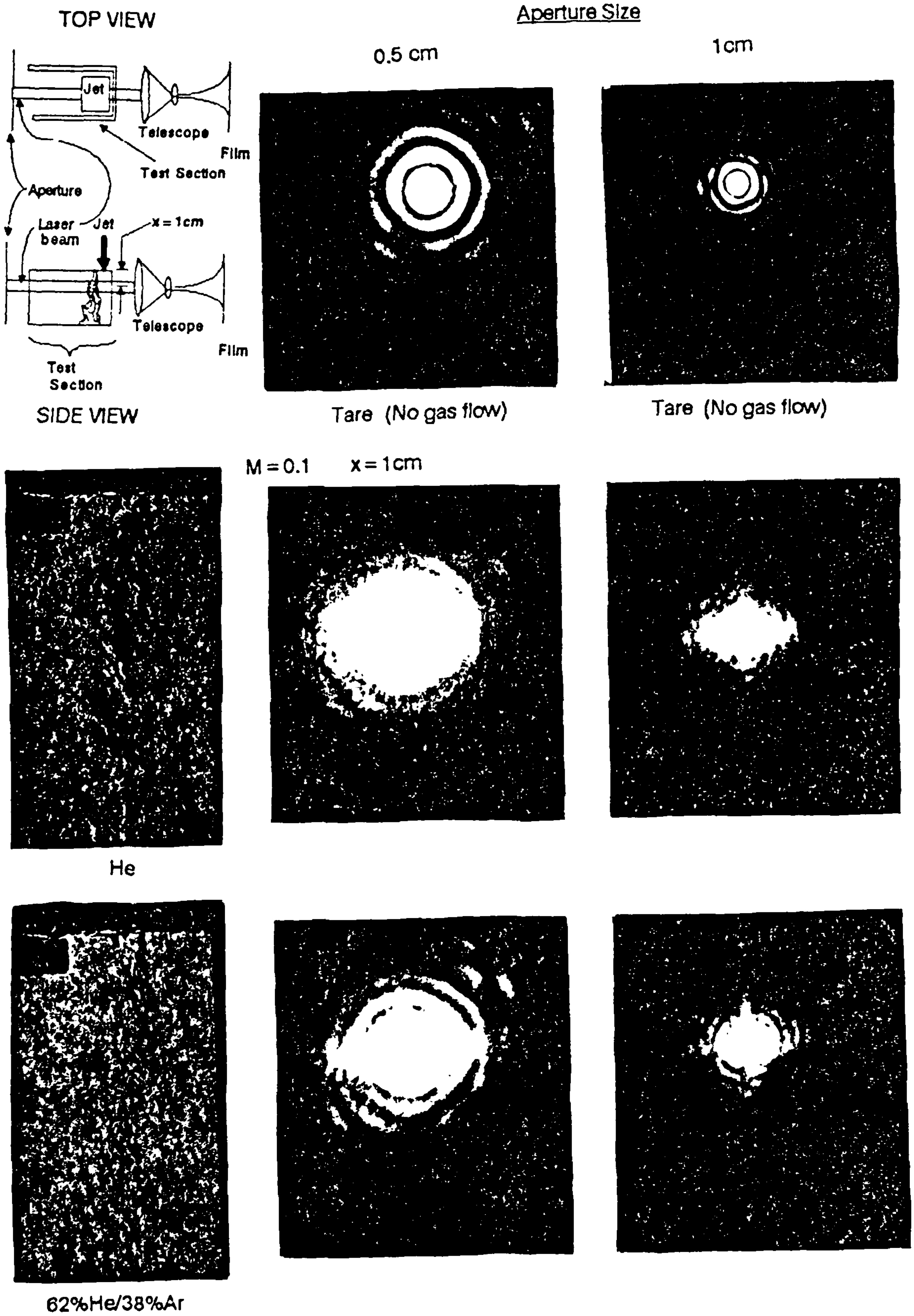


Fig. 3

Preliminary Far Field Observations

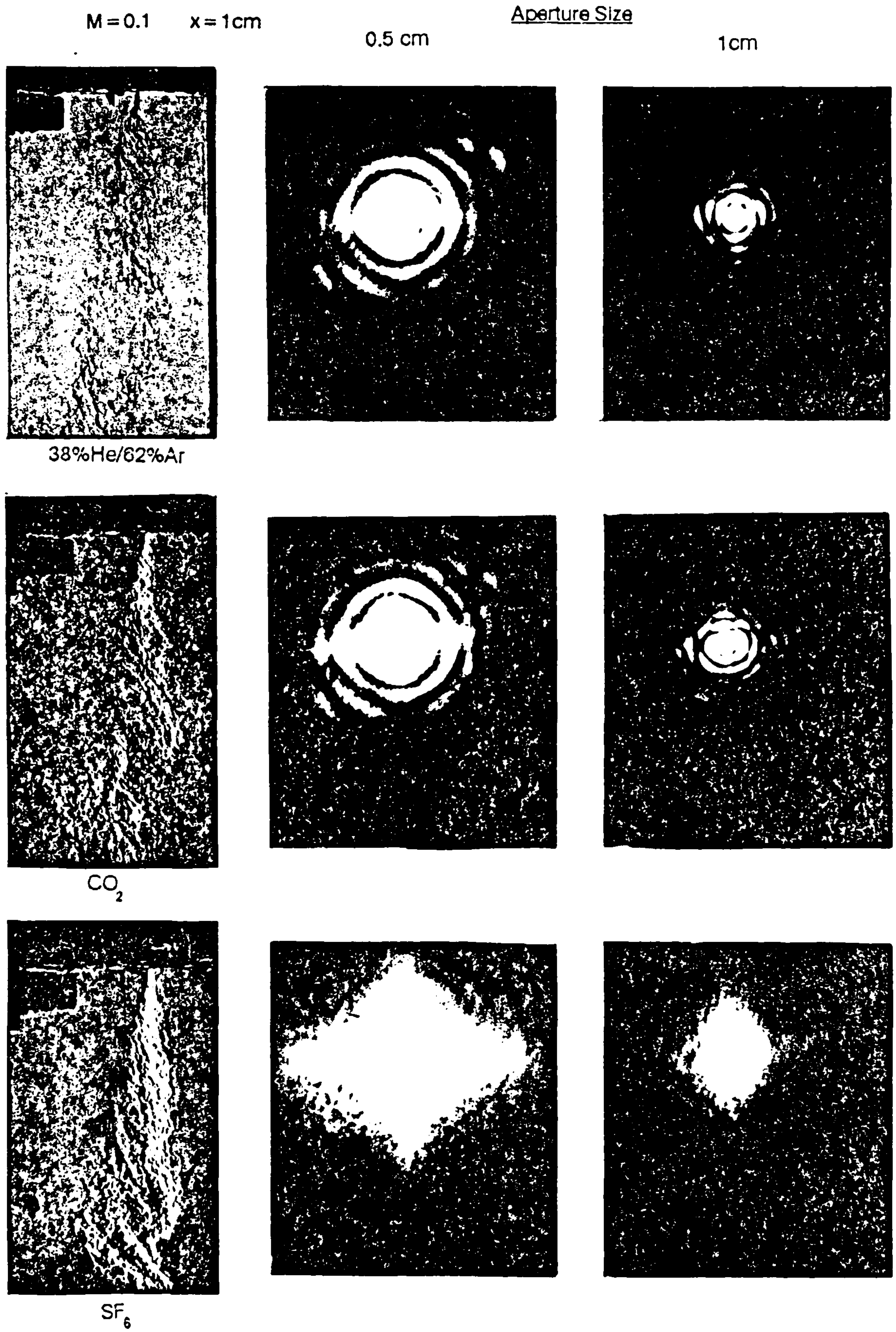


Fig. 3 (continued)

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